QoS-Balancing Algorithm for Optimal Relay Selection in Heterogeneous Vehicular Networks

Aljawharah Alnasser, Hongjian Sun *Senior Member*, *IEEE* and Jing Jiang *Member*, *IEEE*

***Abstract*—Intelligent Transportation System (ITS) could facilitate communications among various road entities to improve the driver's safety and driving experience. These communications are called Vehicle-to-Everything (V2X) communications that can be supported by LTE-V2X protocols. Due to frequent changes of network topology in V2X, the source node (e.g., a vehicle) may have to choose a Device-to-Device(D2D) relay node to forward its packet to the destination node. In this paper, we propose a new method for choosing an optimal D2D relay node. The proposed method considers Quality of Service (QoS) requirements for selecting D2D relay nodes. It employs an Analytic Hierarchy Process (AHP) for making decisions. The decision criteria are linked with channel capacity, link stability and end-to-end delay. A number of simulations were performed considering various network scenarios to evaluate the performance of the proposed method. Simulation results show that the proposed method improves Packet Dropping Rate (PDR) by 30% and delivery ratio by 23% in comparison with the existing methods.**

***Index Terms*—ITS, QoS, relay selection, V2X.**

I. Introduction

IN recent years, automotive manufacturers have developed vehicles that are able to communicate and share information with other smart devices. This has been transforming traditional transportation systems into smart systems, namely, Intelligent Transportation Systems (ITS). In ITS, the communications between various road entities are called Vehicle-to-Everything (V2X) communications. LTE-V2X (release 14) is one of the main communication protocols that support V2X communications [1].

LTE-V2X was developed to provide V2X services and give the road entity the ability to establish two types of links: cellular link, and Device-to-Device (D2D) link. The cellular link is established between the road entity and the infrastructure unit [2]. The D2D link is a direct link between the road entities. D2D (or side-link) is used in three scenarios [3]. First, *in-coverage scenario* where D2D communication is established between two road entities that are located within the network coverage. It is managed by an evolved Node B (eNB) for load balancing or content sharing. Second, *relay coverage scenario* where D2D communication is established between road entities, where one of them is located out of the network coverage, to deliver the packets to the eNB. The relay nodes act as a range extender [4]. Third, *out-of-coverage scenario* where D2D communication is established by road entities which are located out of the network coverage. It is used for sending event messages, periodic messages and sharing content.

In a relay coverage scenario, choosing a D2D relay node that achieves Quality of Service (QoS) requirements is still a challenge in V2X communications [3]. D2D links are used in various applications such as safety-related applications and traffic-related applications. The packet has information about accidents or warnings in the road which helps other drivers to change routes when the packet arrives in a reasonable time as shown in Fig.1. Thus, choosing an optimal link reduces the connection loss and ensure packet delivery in a short time. There is several research on evaluating the quality of side-link in vehicular networks. For instance, Li *at el.* [5] proposed an adaptive QoS-based routing for vehicular networks. It adaptively determines the intersections through which packets move to the destination. The selected route should obtain the best QoS metrics including connectivity probability, packet delivery ratio and delay. Fekair *et al.* [6] developed a QoS-based routing protocol to support data traffic in real-time and multimedia applications with specific QoS requirements. A multi-constraint routing algorithm was proposed to select the best path that achieves QoS requirements, such as required bandwidth, maximum delay and jitter, and minimum link expiry time. Sun *et al.* [7] developed an adaptive routing protocol based on QoS and vehicular density in urban environments. It assists vehicles to find the best path that meets QoS requirements such as hop count and link duration. Eiza

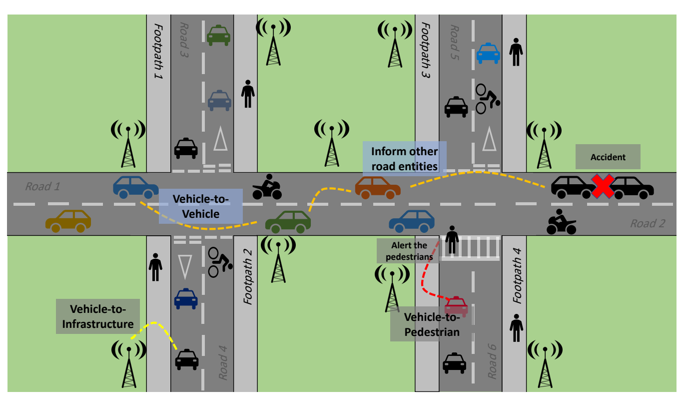

Fig. 1: Applications for vehicular networks

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A. Alnasser is with the Department of Information Technology, King Saud University, Riyadh, KSU, 11543, e-mail: alalnasser@ksu.edu.sa.

H. Sun is with the Department of Engineering, Durham University, Durham, UK, DH1 3LE, e-mail: hongjian.sun@durham.ac.uk.

J. Jiang is with the Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle upon Tyne, UK, NE1 8ST, e-mail: jing.jiang@northumbria.ac.uk

and Ni [8] applied the evolving graph theory to improve the communications. A reliable routing scheme was proposed to support QoS metrics in the routing process from the source to the destination. Recently, Cao *et al.* [9] studied a robust relay selection method in vehicular networks to spread the message with the maximum speed in a wide range of vehicle densities, and proposed a mini-black-burst-assisted mechanism to reduce the partition latency.

Some researchers aimed to improve the performance of existing routing algorithms to achieve QoS in vehicular networks. For example, Bitam and Mellouk [10] suggested a topology-based algorithm that supports the QoS for vehicular networks. It is based on the idea of autonomic bee communication in their food-searching behaviours. Fekair *et al.* [11] proposed a QoS-based unicast routing protocol for vehicular networks. It consists of two phases: a clustering phase that manages the exchange of the routing information based on QoS requirements, and a routing phase that applies an artificial bee colony algorithm to determine the best route based on QoS criteria. Eiza *et al.* [12] adopted the situational awareness concept and developed an ant-colony-system-based algorithm to realise a situation-aware routing algorithm that support QoS for vehicular networks. It is suggested to evaluate potential paths between two vehicles subject to multiple QoS constraints and then choose a best-computed path. Alkharasani *et al.* [13] proposed an enhancement to the mechanism of Optimised Link State Routing Protocol, named Cluster-based Adept Cooperative Algorithm, where each vehicle estimates a reliable low-overhead path using the cluster-based QoS algorithm. The reliable path is chosen based on a signal strength beacon and the mobility degree of a node. Zhang *et al.* [14] used a genetic algorithm to propose a QoS routing protocol that achieves the QoS requirements during the link establishment between vehicles in VANET. The proposed solutions evaluated communication links using criteria that are related to the node mobility in vehicular networks, such as direction and speed. Torrent-Moreno *et al.* [15] developed two algorithms for reducing the beaconing load on the channel and prioritising emergency information delivery in Vehicle-to-Vehicle (V2V) communications. However, they focused on achieving reliable connection for V2V links that are supported by IEEE802.11p. IEEE802.11p has different link and network structure than LTE-V2X. For instance, the link bandwidth in IEEE802.11p is less than that of LTE-V2X, meanwhile, the transmission power in LTE-V2X is lower than that of IEEE802.11p.

To improve the link quality in vehicular networks, various methods were proposed for utilising D2D communications in LTE. For instance, Liu *et al.* [16] studied a D2D communication load balancing algorithm where the D2D device uses D2D relay node to deliver its packets to the eNB in case of congested cells. Also, Liu *et al.* [17] suggested a D2D communication-based algorithm to improve the quality of experience in LTE-A. Additionally, they pointed out that most of D2D communication algorithms did not consider the speed and directions for choosing the best D2D relay node. Tata and Kadoch [18] proposed a multi-path routing algorithm for D2D communications in heterogeneous networks. It is an improvement of Ad-hoc On-Demand Multi-path Distance Vector scheme that evaluates the available bandwidth while choosing the best route. Bastos *et al.* [19] suggested a network assisted routing algorithm in 5G to make a decision regarding the best link to the base station. The link evaluation is based on the number of hops and the channel quality. It was suggested to balance the load on various base stations. In addition, Yang *et al.* [20] designed a D2D bearer control architecture for D2D communications in LTE-A infrastructure. The data offloading decision is made by the eNB or above. Then, the eNB notifies candidates to conduct a discovery process. As the User Equipments (UEs) come into the proximity of each other, D2D session is switched to a D2D link. When the path is no longer available, they switch back to the cellular link. In addition, Wu *et al.* [21] studied a two-level clustering approach. The first level applies fuzzy logic to determine the cluster heads. It considers three factors which are velocity, leadership and signal quality. The second level utilises Q-learning algorithm for choosing which cluster heads can act as a gateway between V2V and LTE. However, most of these methods were applied on old versions of LTE-A, and did not fully consider the high node mobility during the link evaluation.

To overcome these limitations, our recent work [22] proposed an Analytic Hierarchy Process (AHP)-based algorithm for the relay selection in V2X communications, where the link evaluation was based on three factors, i.e., link stability, channel capacity and end-to-end delay. In this paper, we expand the study significantly by evaluating the Packet Dropping Rate (PDR) and end-to-end delivery ratio with various number of nodes, nodes' speeds and transmission ranges. In addition, we study the outage probability for vehicular network (LTE-A). This paper makes three main contributions as shown below:

1) Different from existing research, this paper proposes a QoS-balancing relay selection algorithm for V2X communications by considering the channel model of LTE-V2X (release 14) protocol. Five criteria, i.e., channel capacity, acceleration, direction, hop count and queue size, are considered.
2) An AHP algorithm is applied for the first time to choose the optimal relay nodes in vehicular networks. Based on the performance evaluation, the results show that the proposed method improves the PDR by 30% and delivery ratio by 23%.
3) The outage behaviour probability is studied for the LTE-V2X (release 14) communication protocol. This probability is examined by linking it with the distance, the Signal-to-Noise (SNR) and the SNR threshold. To the best of authors' knowledge, such a detailed and quantitative study is not available anywhere in the literature.

The paper is organised as follows. In Section II, we describe the proposed system model including the considered scenarios and path-loss model. In Section III, we present a detailed description of the proposed relay selection method. In Section IV, we study the outage behaviour probability. In Section V, we conduct various simulations to measure the model performance and compare it with the existing methods. Finally, Section VI concludes the overall work.

II. SYSTEM MODEL

A. The considered network

The considered network is a V2X network with a number of road entities and RSUs. Road entities include vehicles, pedestrians, cycles and motorcycles. The proposed relay selection method focuses on the messages that are destined to the eNB, such as Internet services for updating maps, downloading a video or doing a transaction. Therefore, the road entity may need to use a multi-hop route to deliver its packets to the nearest eNB in some cases such as:

- *Signal weakness:* when the road entity has a connection with the eNB but the signal is weak, e.g., due to the long distance between UE and eNB or the existence of obstacles.
- *Out-of network coverage:* when the road entity is located out of the eNB cell which is called edge node. Therefore, it has to establish links with neighbouring entities to relay the packets to the eNB.
- *Load balancing:* when the road entity is located within the network coverage but it uses a multi-hop route to reduce the cell load [23].

B. Path Loss Model

The dynamic movement of road entities causes a frequent change in the network topology. Thus, it has a high impact on the channel state. Therefore, we have to take these factors into account in the channel model. This work builds on 3GPP Release 14. By October 2020, new 3GPP releases are in progress that cover more V2X application layer services. For instance, Release 16 aims to develop more advanced use cases beyond LTE V2X, and 5G NR operations in ISM bands. In these use cases, either low-latency communications or high data delivery ratio would be required that reiterates the importance of this work. But it is worth noting that channel models in (Eq.3-Eq.5) may need some update depending on these new releases recommendation. This would be a good direction for future research.

As the main focus of the algorithm is to choose the relay node in multi-hop route, we only study the communication in a rural area for the line-of-sight scenario to have more multi-hop routes between source and destination. We use the channel model of LTE-V2X (Release 14) [24]. The average path-loss PL at a distance $d_{i,j}$ is expressed as follows

$$PL(d_{i,j}) = \begin{cases} PL_1, & d_{i,j} < 10m. \\ PL_2, & 10m \leq d_{i,j} \leq d_{BP}. \\ PL_3, & d_{BP} \leq d_{i,j} \leq 10km. \end{cases} \quad (1)$$

where $d_{i,j}$ is the distance between node i and node j. We assume that the average path-loss ($PL(d_{i,j})$) is equal to PL_1 which is computed by

$$PL_1 = \overline{PL}(d_0) + 10\eta \log_{10}(\frac{d_{i,j}}{d_0}) \quad (2)$$

where η is a path-loss exponent that represents the variation of path-loss and distance. $\overline{PL}(d_0)$ is the mean path-loss at reference point d_0 which is equal to $1\ m$. The second and third cases are based on the channel model in [24]. The average path-loss when the distance $d_{i,j}$ between $10m$ and d_{BP} is expressed as

$$\begin{aligned} PL_2 = 20\log_{10}(\frac{40\pi d_{i,j} f_c}{3}) + min(0.03h^{1.72}, 10)\log_{10}(d_{i,j}) \\ - min(0.044h^{1.72}, 14.77) + 0.002\log_{10}(h) d_{i,j} \end{aligned} \quad (3)$$

where h is the average building height, and f_c is the centre frequency in Hz. The shadowing factor is $\sigma_{SF} = 4$ and d_{BP} is the breakpoint distance which is measured by

$$d_{BP} = \frac{2\pi h_{UE_i} h_{UE_j} f_c}{c} \quad (4)$$

where h_{UE} is the antenna height of UE, and $c = 3.0\times10^8 m/s$. The path-loss in the third case (PL_3), when $d_{i,j}$ is greater than $10\ km$, is measured by

$$PL_3 = PL_1(d_{BP}) + 40\log_{10}(\frac{d_{i,j}}{d_{BP}}) \quad (5)$$

where the shadowing factor $\sigma_{SF} = 6$.

III. AHP-BASED ALGORITHM FOR OPTIMAL RELAY SELECTION IN V2X COMMUNICATIONS

We aim to propose a method for choosing the D2D relay nodes to support QoS. In the proposed method, each road entity will apply an AHP algorithm to make a decision regarding D2D relay nodes. AHP is a multi-metric decision-making algorithm that uses a hierarchical approach to evaluate potential factors [25]. It combines qualitative and quantitative factors in the analysis. The analysis process consists of four steps as follows:

A. First: build a hierarchical model

We design the hierarchical model based on five criteria in level 1 as shown in Fig.2. Level 2 represents the neighbouring nodes. For evaluating these criteria, first we require to set them up in a matrix as follow:

$$A = \begin{bmatrix} C_1^t & D_1^t & H_1^t & Acc_1^t & Q_1^t \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C_m^t & D_m^t & H_m^t & Acc_m^t & Q_m^t \end{bmatrix} \quad (6)$$

where m is the number of available neighbouring nodes. The detailed information and calculation of the five factors are described as follows.

1) Channel Capacity (C^t): As the connection time between two road entities is restricted, high channel capacity is required to ensure packet delivery. We consider three parameters that have a negative impact on the channel capacity, which are shadowing, multi-path propagation and signal noise.

First, we compute the received signal power with the impact of shadowing and multi-path propagation using

$$RP_j(d_{i,j}) = TP_i - (PL(d_{i,j}) + X_\sigma) \quad (7)$$

where RP_j is the received signal power at receiver node j with distance $d_{i,j}$, TP_i is the transmission power with which node i transmits a signal. $X_{\sigma_{SF}} \sim N(0, \sigma_{SF}^2)$ is a random

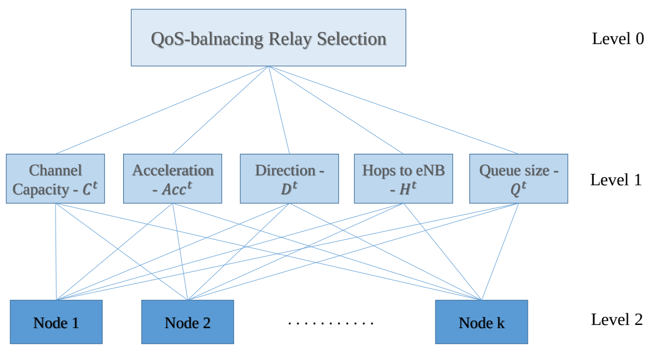


Fig. 2: Structure of AHP reliability model

shadowing effect with a normal distribution with zero mean and σ^2_{SF} variation.

Second, we measure the Signal-to-Noise ratio (SNR_{db}) using

$$SNR_{dB} = RP_j(d_{i,j}) - P_{Noise} \tag{8}$$

where P_{Noise} is the noise signal in dBm. SNR is

$$SNR = 10^{\frac{SNR_{dB}}{10}} \tag{9}$$

Finally, we compute the channel capacity with considering of the noise by

$$C^t = B * \log_2(1 + SNR) \tag{10}$$

where B is the channel bandwidth.

2) Link Stability: The network topology in the vehicular network is frequently changed. Thus, the communication link between two road entities does not last for a long time. Link stability is defined as the duration of link lasts between two road entities. Therefore, if the link lasts longer between two road entities, it minimises the PDR. Link stability is evaluated by two mobility parameters, i.e., acceleration and direction; These mobility parameters are most common criteria when road entity wants to establish D2D link [26], [27]. They are defined as follows.

- **Acceleration** (Acc^t)**:** is the rate of change of velocity of the road entity with respect to time t. Each road entity i measures the difference between its acceleration and the acceleration of the neighbouring entities j. It is computed by

$$Acc^t = \mid a^t_i - a^t_j \mid \tag{11}$$

where a^t_i and a^t_j are the acceleration of node i and node j during a period of time (Δt). The relative acceleration is computed by taking the difference between vehicle's velocity at time t and time $(t - \Delta t)$ [28]. The relative acceleration of each node x is expressed as

$$a^t_x = \frac{v^t_x - v^{t-\Delta t}_x}{\Delta t} \tag{12}$$

where $x \in N$ and N is the list of road entities. v^t_x and $v^{t-\Delta t}_x$ is the velocity of node x during current time t and previous time interval $t - \Delta t$.
- **Direction** (D^t)**:** when the source and destination road entities are moving in the same direction, they provide higher link stability than when they are moving in the opposite directions. Most of routing protocols considered important routing metrics including direction, distance and traffic density metrics to deal multi-hop routing [29]. The opposite entities can be paired when the channel capacity is very high where the packet can be sent before link breakage. The link stability has lower priority in the proposed algorithm because when the link has high capacity, then the packet will be sent in very short time. Thus, the algorithm ensures the packet delivery.

TABLE I: 9-points scale for PCM

Scale	Factors importance
1	Equally important
3	weakly important
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6,8	Intermediate value between adjacent scales

As a result, when the two road entities are moving with very close speed and in same direction that assure link stability between them.

3) End-to-End delay: To enhance the QoS of V2X network, we have to obtain low end-to-end delay for packet delivery. As the road entity sends packets through a multi-hop route, it is necessary to ensure that the packets are delivered in a reasonable time. In addition, considering the short-range communication characteristics between various road entities in the V2X environment, transmission and propagation delay is negligible. Therefore, we consider the two main parameters while choosing D2D relay node which are:

- **Hops to eNB** (H^t)**:** it is used to select a route with less number of hops among the available routes to eNB. Most of the routing protocols in vehicular networks use hop count as the main metric. We assumed that each vehicle knows a number of hops to connect to eNB for all neighbours. The number of hops can be known by a distance vector approach, i.e., exchanging the number of hops with neighbours. This can be achieved by using a side-link transmission as specified in 3GPP release 14 or other types of common control channel; however, these could generate some overhead, particularly in dense networks.
- **Queue size** (Q^t)**:** we evaluate the queue size of the next hop entity to avoid buffer overflow which leads to high PDR. In addition, it is important to minimise queuing time. Thus, the road entity chooses the node with low queuing size as a relay node. The queue size is evaluated based on the remaining empty slots in the queue. Also, we assume that the queue size is shared in the same way as that of number of hops. Exchanging information with neighbours can be implemented by short-range broadcasting, e.g., every 30 second. The buffer overflow could cause an increase in packet dropping rate. Thus, we gave it high priority after the channel capacity.

TABLE II: Pairwise Comparison Matrix

Criteria	C^t $(u=1)$	D^t $(u=2)$	H^t $(u=3)$	Acc^t $(u=4)$	Q^t $(u=5)$	Priority Vector
C^t $(y=1)$	1	6	2	8	4	21%
D^t $(y=2)$	1/6	1	1/4	3	1/3	4.75%
H^t $(y=3)$	1/2	4	1	6	2	13.5%
Acc^t $(y=4)$	1/8	1/3	1/6	1	1/5	1.825%
Q^t $(y=5)$	1/4	3	1/2	5	1	9.75%

B. Second: form Pairwise Comparison Matrix (PCM)

Each element in the criteria level is compared with the other elements. We used the scale of numbers as shown in Table I to determine the importance of one element over the other elements [25]. The proposed five criteria should be evaluated in any circumstances in vehicular networks. Starting by channel capacity, in vehicular networks, the road entity could be blocked by any obstacle. Thus, measuring the channel capacity before sending the data is important in any case either high or low traffic. Second, the acceleration and direction are measured to evaluate the velocity and stability of neighbouring links. Also, these criteria are not limited to special communication scenario where the most of road entities are mobile nodes. In addition, the delay of communication is measured because of the short connection in vehicular networks which is represented by number of hops and queue size. The pairwise matrix was filled in a fixed way based on the priority vector. We gave the channel capacity the highest priority. In addition, the consistency ratio is measured to achieve value lower than 10%. Building dynamic matrix degrade the algorithm performance by adding additional time for creating the matrix at each communication. The values of Table II is filled in a matrix for calculations as follows

$$PCM = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ \vdots & \vdots & \vdots & p_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix},$$
$$p_{yy} = 1, p_{uy} = 1/p_{yu}, p_{yu} \neq 0 \tag{13}$$

where n is the number of criteria.

C. Third: measure the weight vector of decision factors

We measure the normalized relative weight matrix (B) by dividing each element of the matrix (A) with the sum of its column

$$B = Normalized(A) \tag{14}$$

After that, we calculate Y matrix which represents the importance degree of alternatives (potential links) as follows

$$Y = B.\overrightarrow{ePCM} \tag{15}$$

where $\overrightarrow{ePCM}$ is the eigenvector of PCM.

D. Fourth: make a consistency test for the PCM

The consistency is expressed by the following equation, and the measure of consistency is called the consistency index (CI)

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{16}$$

where λ_{max} is the maximum eigenvalue of PCM. The Random Inconsistency (RI) [25] is computed by

$$RI = \frac{1.987 \times (n-2)}{n} \tag{17}$$

Finally, we have Consistency Ratio (CR) as follows

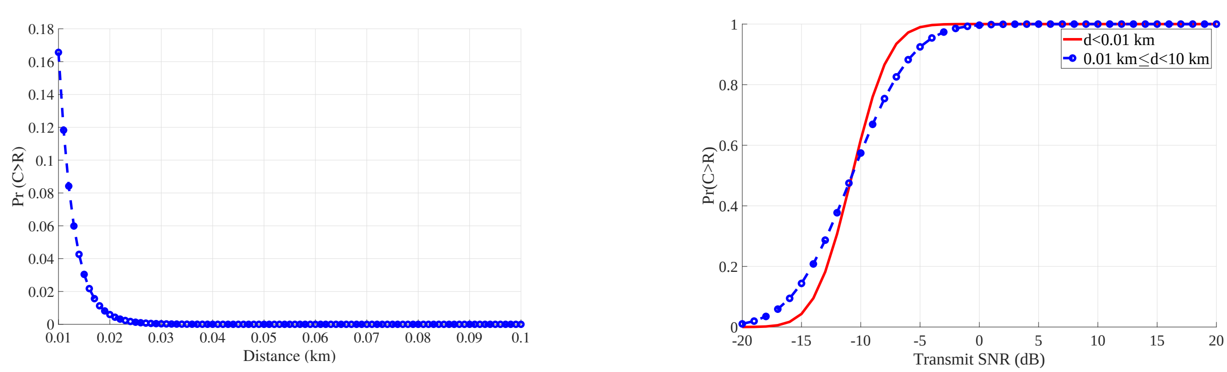
$$CR = \frac{CI}{RI} \tag{18}$$

In AHP algorithm [25], if the value of CR is smaller or equal to 10%, the inconsistency is acceptable. If the CR is greater than 10%, we need to revise the PCM. In the proposed model, we compute the CR which is equal to 2.96%.

IV. Outage Behaviour Probability

A. Outage probability with variable channel capacity

Outage probability of a communication channel is the probability that a given data rate is not supported because of variable channel capacity. Outage probability is defined as the



(a) Various distance

(b) various transmit SNR

Fig. 3: Outage probability of a communication channel: a) with various distance; b) with various transmit SNR.

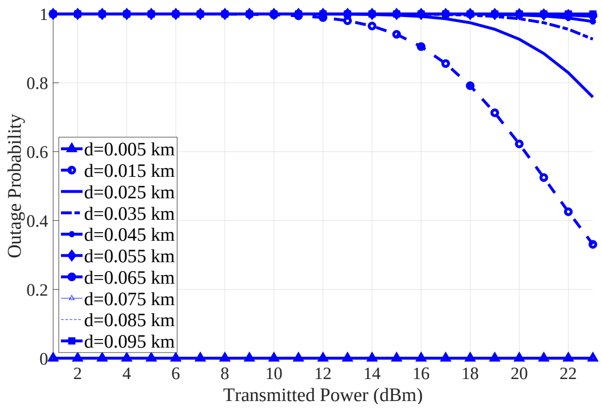


Fig. 4: Outage probability versus transmitted power

probability that data rate is less than the required threshold data rate. The required threshold data rate (R) is computed using

$$R = \frac{PcktSize}{time_{trans}} \tag{19}$$

where $PcktSize$ is the packet size and $time_{trans}$ is the required transmission time. As much as the packet size increases, the transmission time increases. Thus, the connection time between two entities should be longer to be able to receive the whole packet without any disconnection.

Here, we study the probability of the communication channel is enough for sending the packet in a predefined time. The probability is computed using Eq.7 and Eq.10 as follows

$$\begin{aligned}&P_{out}[C > R] \\ &= P_{out}[B\log_2(1 + SNR) > R] \\ &= P_{out}[SNR_{db} > 10\log_{10}(2^{\frac{R}{B}} - 1)] \\ &= P_{out}[X_\sigma < TP - PL - P_{Noise} - 10\log_{10}(2^{\frac{R}{B}} - 1)] \\ &= P_{out}[X_\sigma < \beta]\end{aligned} \tag{20}$$

As the probability follows Gaussian distribution, it is computed by

$$P[X_\sigma < \beta] = \frac{1}{\sqrt{2\pi}\sigma}\int_{-\infty}^{\beta} e^{-\frac{y^2}{2\sigma^2}} \quad dy \tag{21}$$

We measure the probability of having enough channel capacity for data transmission. In Fig.3 (a), we study the impact of various distance on the channel capacity. We notice that the probability is very low when the distance is greater than or equal $10m$. If the bit rate has high priority for a specific message, the distance between two road entities should be less than $10m$. In Fig.3 (b), we examine the probability for various transmitted SNR. We consider two cases of distance because they having different path-loss computation as shown in eq(1). We make the following remarks:

- as long as the transmitted SNR increased, the probability of having the required data rate is increased.
- the probability is greater than 50% when the transmitted SNR is greater -10 dB until it reach 100% when the transmitted SNR is greater than zero;
- in case the distance less than $10m$, the probability reach 100% before the other case of distance range.

B. Outage probability versus transmitted power

Because some road entities has a limited battery, they may send the packet with low transmission power to save energy. As a consequence, we measure of probability of link outage with various transmission power and distance. It is computed using Eq.7 as follows

$$\begin{aligned}P_{out}[RP < P_{th}] &= P_{out}[TP - PL - X_\sigma < P_{th}] \\ &= P_{out}[X_\sigma > TP - PL - P_{th}] \\ &= P_{out}[X_\sigma > \beta]\end{aligned} \tag{22}$$

where P_{th} is the receiver sensitivity. The probability expresses as Q-function in term of the complementary error function as follows

$$P[X_\sigma > \beta] = Q(\frac{\beta}{\sigma}) \tag{23}$$

The outage probability gives us the chance to determine the optimal distance for acceptable signal as shown in Fig.4. The outage probability values are zeros for distance less than $10m$ for any transmission power. It means that the signal quality is good at the receiver. However, as much as the distance increase the outage probability is increased. When the distance between the sender and receiver is increased, the road entity require to increase the transmission power to guarantee good signal.

C. Signal-to-Noise Ratio

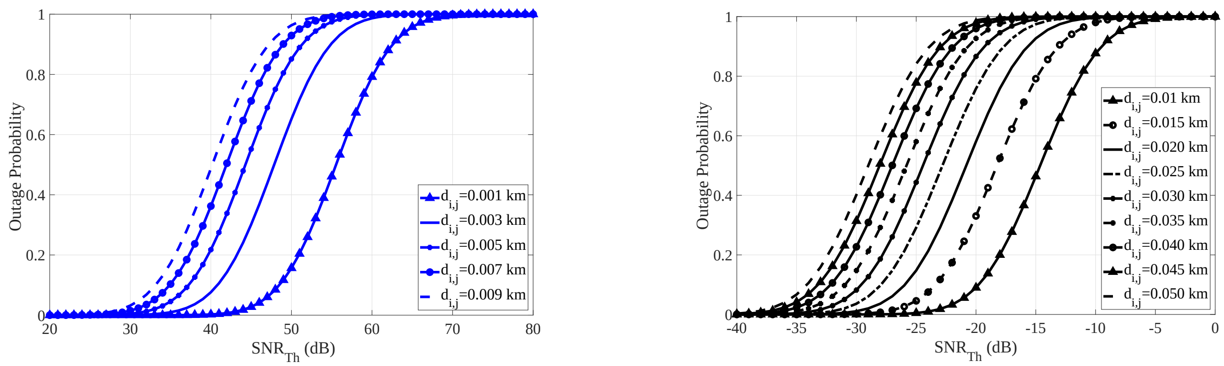
1) Outage probability versus SNR threshold (SNR_{Th}): In vehicular network, the signal could be affected by various obstacles such as large truck and buildings. Thus, the signal should have less noise when it is received. As a result, we measure of probability of link outage with various values of SNR_{Th} and distance. It is computed using Eq.7 as follows

$$\begin{aligned}&P_{out}[RP < P_{th}] \\ &= P_{out}[TP - PL - X_\sigma - P_{Noise} < SNR_{Th}] \\ &= P_{out}[X_\sigma > TP - PL - P_{Noise} - SNR_{Th}] \\ &= P_{out}[X_\sigma > \beta]\end{aligned} \tag{24}$$

In Fig.5 (a), we notice that we have low outage probability when the distance between road entities is less than 10 m. The link has 100% of outage probability only when we have high SNR threshold such as 55 dB. On the other hand, when the distance is greater than 10 m between road entities, we have to set low thresholds to be able to achieve low outage probability as shown in Fig.5 (b).

2) Outage probability versus transmitted SNR: Here, we measure of probability of link outage of the transmitted signal with various values of SNR_{dB}, SNR_{Th} and distance. It is computed using Eq.7 as follows

$$\begin{aligned}&P_{out}[RP < P_{th}] \\ &= P_{out}[TP - PL - X_\sigma - P_{Noise} < SNR_{Th}] \\ &= P_{out}[X_\sigma > SNR_{dB} - SNR_{Th}] \\ &= P_{out}[X_\sigma > \beta]\end{aligned} \tag{25}$$



(a) Distance$< 10m$ (b) Distance $\geq 10m$

Fig. 5: Outage probability versus SNR threshold (SNR_{Th}) (dB): a) Distance$< 0.01km$; b) Distance $\geq 0.01km$

In Fig.6, we notice that as long as we have lower SNR threshold, the outage probability decreases for various transmit SNR. There is a small difference in curves in (a) and (b) where higher distance cause higher outage probability.

V. Performance Evaluation

We use the existing model [21] as a benchmark to evaluate the performance of the proposed model. Based on literature review in Section I, most of existing works were proposed for VANET where all communication is supported by IEEE802.11p. The remaining research proposed relay selection in D2D communication. However, they are considered old versions of LTE where the mobility of the nodes is very slow in most cases. In the existing model [21], the LTE-A is applied for the communication between road entities and base station. The choosing of the gateway nodes is based on various mobility specification such as velocity and signal quality. In addition, the gateway chosen based on the LTE bandwidth which at least consider some of LTE-A specifications. In this section, we compare the two models in two metrics which are PDR and end-to-end packet delivery ratio.

A. Model definition

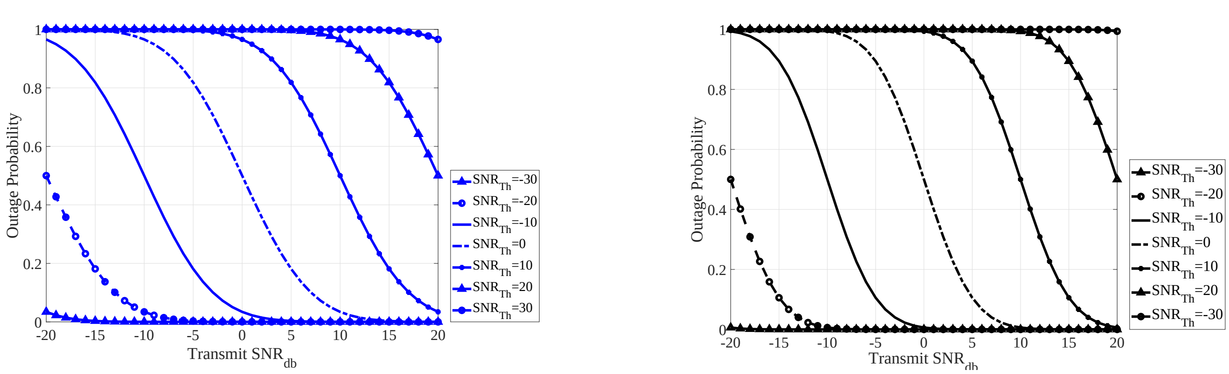
The existing model suggested a hierarchical approach to decide if a vehicle should act as a gateway or not. In the first level of clustering, they proposed the fuzzy logic algorithm to choose cluster heads. Then, they applied the Q-learning algorithm to choose some of cluster heads as gateways between IEEE802.11p with LTE networks.

1) Fuzzy logic algorithm: The competency value calculation consists of three steps. First, the velocity factor, leadership factor, and signal quality factor are calculated for each one-hop neighbour who is within the range of 1/2 R.

2) Q-learning algorithm: They used a Q-learning algorithm to determine whether a cluster head should work as a gateway or not. The Q-value for a given action is determined by the discounted reward. If a vehicle is directly connected to the base station, the vehicle can get a positive reward. However, the value of the reward is decreased with the increase of the number of devices.

B. Simulation Set-up

We used MATLAB to conduct the simulation of a V2X network with 100 road entities and 6 RSUs with parameters as shown in Table III. The road entities move over an area of $800 \times 800\ m^2$ with various speed ranges as shown in Table IV. The road entity sends the transaction message to the core network directly or using a multi-hop routing protocol as shown in Fig.7. In addition, the considered network has heterogeneous nodes where the road entity includes vehicles, pedestrians, motorcycles and cycles. We assumed that each



(a) Distance$< 10m$ (b) Distance $\geq 10m$

Fig. 6: Outage probability versus transmit SNR (dB): a) Distance$< 0.01km$; b) Distance $\geq 0.01km$

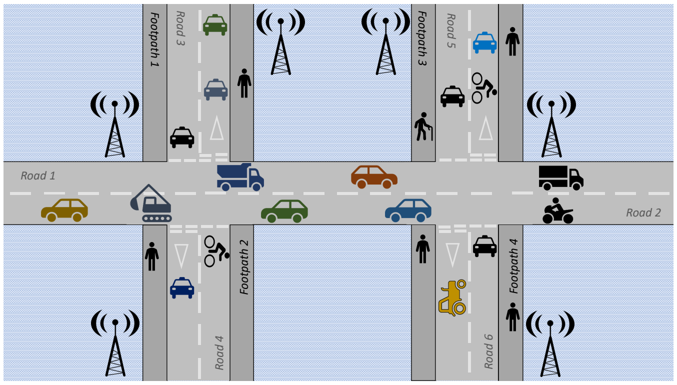


Fig. 7: Simulation area

TABLE III: Simulation Parameters

Parameter	Value
Simulation time	224 sec
Simulation area	8000 $\times$ 800 m^2
Number of nodes	100
Number of RSUs	6
Noise	-90 dbm
Frequency Band	5855-5925 MHz [24]
Bandwidth	70 MHz [24]
Packet size	510 Bytes
Transmission time	500 μsec
Transmission Power	23 dbm [30]
Road Entity Transmission Range	250 m
RSU Transmission Range	500 m
Antenna height for UE h_{UE}	1.5 m [24]
Average building height h	5 m [24]
Queue size	25 packets
Number of sub-channels	2
MCS Scheme	QPSK
MCS Index	7
Channel Busy Ratio (CBR)	0.5

one simulation run time is equal to 1 second in real implementation.

To validate our simulation results, we compare the simulation results of the existing model with their validated results [21] as shown in Fig.8. We notice that the simulation results are very close to the validated one in both average V2V hops and the number of gateway nodes.

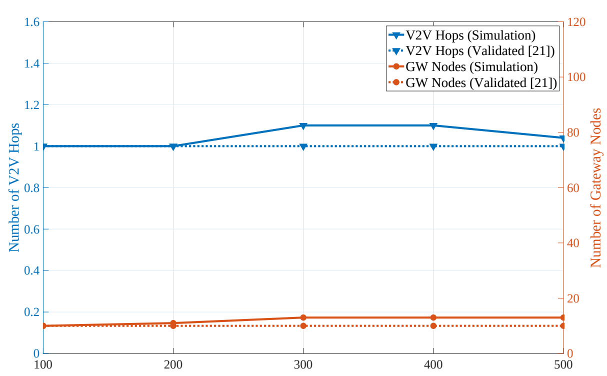


Fig. 8: Validation results for average V2V hops and number of gateway nodes

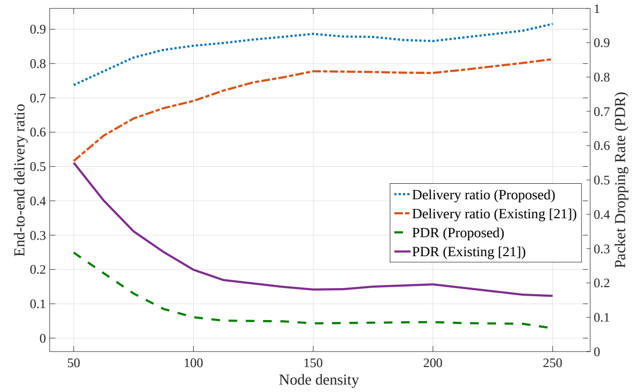


Fig. 9: Impact of node density on end-to-end delivery ratio and PDR

TABLE IV: Mobility Parameters

Road Entity	Speed range
Vehicle	[54-72] km/h
Motorcycle	[54-72] km/h
Cycle	[3.6-14.4] km/h
Pedestrian	[3.6-4.32] km/h

C. Experiment Results

We evaluate the network throughput by measuring two main metrics which are PDR and end-to-end packet delivery ratio. PDR is the rate of the packets that are generated but not delivered to the designated road entity. PDR evaluates the link between each two road entities. It is computed by

$$PDR_{i,j} = \frac{NI_{i,j}}{TI_{i,j}} \tag{26}$$

where $NI_{i,j}$ and $TI_{i,j}$ are the negative interactions and the total interactions between road entity i and road entity j respectively.

On the other hand, end-to-end packet delivery ratio represents the percentage of the arrived packets to the core network. It is measured by

$$DR = \frac{GP}{AP} \tag{27}$$

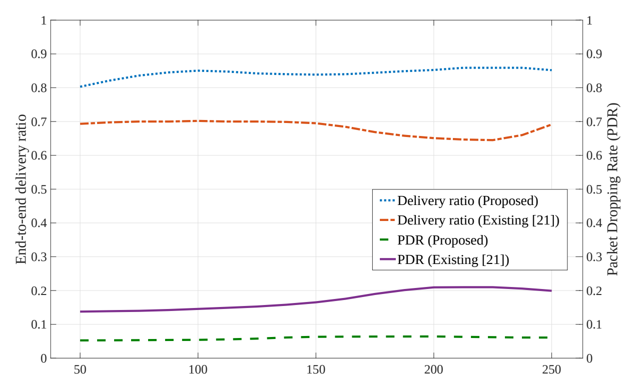


Fig. 10: Impact of road entity transmission range on end-to-end delivery ratio and PDR

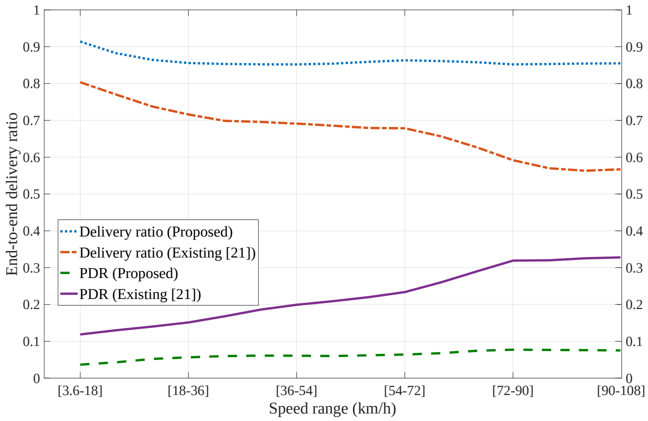


Fig. 11: Impact of road entity speed on end-to-end delivery ratio and PDR

where GP is the total generated packets of all road entities and AP is the number of arrived packets to the core network.

1) Impact of node density on delivery ratio and PDR: We study the impact of node density on end-to-end delivery ratio and PDR as shown in Fig.9. We notice that the delivery ratio increases when the number of road entity increases. This is because of the availability of various neighbours to deliver the packets to the core network. The proposed model achieve high delivery ratio which around 92% when the number of road entities is equal to 250. On the other hand, PDR decreases when the number of road entities goes up. High number of road entities means that the road entity has broad choices to evaluate and choose the most stable link. In the proposed model, PDR is very low when the number of road entities exceeds 100 entities to reach to 3% when number of road entities is equal to 250. However, the PDR in the existing model quite high where it reach 12% in the best case.

2) Impact of road entity transmission range on delivery ratio and PDR: Various transmission range of road entity affect on the detecting range of neighbouring nodes (relay nodes). Short range leads to less number of neighbouring nodes. Thus, the road entity has few links to relay packets to the core network. In Fig.10, we study the impact of different transmission ranges on delivery ratio and PDR. We notice that the ratio in the proposed model increases when the transmission range increases. On the other hand, the ratio in the existing model goes down because the range of electing cluster heads and gateways increases, thus, less number of gateway is existed. In addition, we notice that the PDR in the proposed model is stable and not affected by transmission range which achieve very low PDR that equal to 6%. However, the PDR increases when the transmission range increases in the existing model because the large distance to the gateway gives higher outage probability. We conclude that the road entity in proposed model always chooses the optimal link and consider the distance to the relay node.

3) Impact of road entity speed on delivery ratio and PDR: The link outage that caused by node mobility is the most challenge in vehicular network. As a consequence, we study the impact of road entity speed on the end-to-end delivery ratio and PDR. In Fig.11, we notice that the delivery ratio goes down when the entities' speed increases in both models. However, the proposed model slightly decreases and achieves acceptable ratio which around 85% of packets are arrived to the core network. The drop in delivery ratio in the existing model is higher than the proposed model which approximately reaches to 57%. On the other hand, the PDR increases when the speed increases in the existing model to reach 33% in the worst case. On the other hand, PDR in the proposed model slightly increases when the speed increases. As a result, the link stability in the proposed model is better than the existing model where the PDR is not highly affected by road entity speed.

VI. Conclusion

In this paper, we proposed an AHP-based algorithm for optimal relay selection in V2X communications. Several criteria were considered to evaluate the link quality, including channel capacity, link stability, and end-to-end delay. The proposed algorithm was applied on V2X network that has various number of road entities.

Most of existing methods were proposed for VANETs which have different bandwidth and transmission power than those of V2X networks. Some other research ignored high node mobility during the link evaluation. Thus, this new method was proposed to overcome the limitations in the exiting methods. It combined the most important criteria in vehicular networks with different priorities, such as channel capacity, direction, acceleration, hop count and queue size. Simulation results showed that the proposed method can improve PDR by 30% and delivery ratio by 23% in comparison with the existing method.

In addition, the outage probability behaviour was studied based on the channel model in LTE-V2X (release 14). Then, a number of simulations were conducted to evaluate the performance of the proposed method. We studied the impact of various factors, such as the number of road entities, the entity's transmission range and the entity's speed on PDR and delivery ratio.

In future work, new criteria could be implemented to study the impact of other parameters, such as errors due to half-duplex transmissions, and errors due to packet collisions with non-line-of-sight scenarios, on PDR and the end-to-end delivery ratio. We will also add trust criteria that we proposed in [31] for choosing the optimal relay link. Trust will measure the trustworthiness of nodes and avoid the route through malicious nodes.

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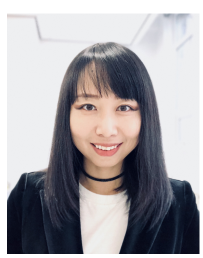
Dr Aljawharah Alnasser is an assistant professor at the Information Technology Department, King Saud University, Saudi Arabia. She received the M.Sc. degree in computer engineering from King Saud University (Saudi Arabia) in 2015. Also, she received Ph.D. degree in computing sciences from Durham University (U.K.) in 2020. Her current research interests include trust management in Internet of Things, wireless communications, and vehicular networks.

Prof. Hongjian Sun (Senior Member, IEEE) received the Ph.D. degree in Electronic and Electrical Engineering from the University of Edinburgh, U.K., in 2011. He held post-doctoral positions with King's College London, U.K., and Princeton University, USA. Since 2013, he has been with the University of Durham, U.K., as Professor (Chair) in Smart Grid, Associate Professor (Reader) in 2017-2020, and Assistant Professor in 2013-2017. He has authored or co-authored over 120 papers in refereed journals and international conferences. He has made contributions to and co-authored the IEEE 1900.6a-2014 Standard. He has authored or co-authored five book chapters, and edited two books: IET book *Smarter Energy: From Smart Metering to the Smart Grid*, and CRC Book *From Internet of Things to Smart Cities: Enabling Technologies*. His research mainly focuses on: 1) smart grid: communications and networking; 2) smart grid: demand side management and demand response; and 3) smart grid: renewable energy sources integration.

He is an Editor-in-Chief for *IET Smart Grid journal*, and an Editor for *Journal of Communications and Network*. He also served as a Guest Editor of the *IEEE Communication Magazine*, and the *IEEE Transactions on Industrial Informatics for several feature topics*.



Dr Jing Jiang (Member, IEEE) is a Senior Lecturer at the Department of Mathematics, Physics & Electrical Engineering, and joined Northumbria University at Newcastle in Sept. 2018. She received her Ph.D. degree in Electrical and Electronics Engineering from the University of Edinburgh (U.K.) in 2011. From 2011 to 2018, she was a Research Fellow with the Centre for Communication Systems Research, University of Surrey, and then a Research Associate with the Department of Engineering, Durham University, U.K.

Her current research interests include Next Generation Wireless Systems, Smart Grids, Cyber Security in Smart Grid Systems, Vehicle-to-Everything Communications, Cognitive Radio Networks, and Internet of Things in Smart Energy Applications. She is a subject editor of *IET Smart Grid Journal*, associate editor of *EURASIP Journal Wireless Comm. and Net.*, and associate editor of *IET Communications Journal*.